Understanding, modeling and controlling wine fermentation

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Triggered by the increasing environmental issues we are currently facing, the agrifood industry has been undergoing a major transformation towards sustainable practices. Newer societal concerns are increasingly becoming significant for the wine industry, related to aspects such as the energy consumption of the fermentation process, or the reduction of the carbon footprint. Behind this paradigm change, there is the need to preserve the quality of the end product. In this sense, aromas are among the most important factors that determine the character and quality of wine. They are a consequence of the aroma compounds that are synthesized during fermentation, which are highly volatile chemical products responsible for the taste and flavor of the final product. In practice, reducing the energy footprint without neglecting wine quality is a very complex task that requires a complete study of the process—from the development of novel mechanistic models to the design of breakthrough real-time control strategies—to find a suitable trade-off between these two key aspects. While the complexity of the aromatic profile of wine depends on many factors related to fermentation management practices, two elements have a particular weight : the nitrogen concentration in the must and the temperature profile during the fermentation process. In recent years, complex and computation-intensive real-time optimization and control tasks are increasingly being implemented in the form of digital twins, to better understand and assist the decision-making of complex processes. In this context, we are currently exploring fundamental aspects of alcoholic fermentation from a systems perspective, towards the first digital twin of the oenological fermentation process. This includes building mechanistic models of the bioprocess, state estimation from on-line measurement [1], multiobjective optimization targeting specific aromatic profiles and energy objectives [2], and real-time control strategies relying on time-varying temperature profiles during the fermentation process.

[1] M. Fleurial, L. Sacchelli, A. G. Yabo. *State estimation in alcoholic fermentation models : a case-study in wine-making conditions.* In *2024 European Control Conference (ECC)*, pp. 412–417. IEEE, 2024.

[2] A. G. Yabo, C. Casenave. *Aroma synthesis and energy consumption in wine fermentation : a multiobjective optimization approach.* IFAC-PapersOnLine, **56(2)**, 6211–6216, 2023.

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